level, and the hours of observation. The hours are not given, nor the heights of the places above sea-level, nor the months included in the seasonal periods. All these things may be of no interest to the sailor who will be expected to test the charts by his experience, but they are vital to the utilisation of the author's work by other meteorologists either for research or for incorporation in charts for wider areas.

The tables of wind give (1) for sixty-six places the "mean direction" of the wind for each season and the year, computed probably from Lambert's or some similar formula; (2) for seventeen regions of the Mediterranean the frequency of light, moderate, and strong winds for sixteen points of the compass, and the number of calms, also for each season and the year. The regions are roughly about 200 miles square.

The charts have been drawn with a great deal of care and the delineation is clear and attractive. They are on a relatively large scale, and consequently are folded into the book, which makes it troublesome to consult them, but the reader will feel that his trouble is compensated by the ease of seeing rapidly the general features and the details of the meteorological distribution. It may be remarked, however, that charts of normal distribution intended for the seafaring man ought to be printed on good linen-backed paper if they are to be used and not folded and put away in a drawer until a new set is received. Indeed, it is doubtful if the ordinary navigating officer will consult meteorological charts regularly until they are made part and parcel of his everyday equipment by being printed on his navigating charts.

Prof. Marini's charts showing the wind roses for the seventeen regions referred to, are very interesting, bringing out most clearly the relatively stormy winter conditions of the western Mediterranean and the great preponderance of winds from nearly due east or due west between Sardinia and Gibraltar. No wind rose is given for any part of the Adriatic. E. G.

LORD KELVIN'S WORK ON GYROSTATICS.[1]

I.—*Gyrostatic Experiments in the Glasgow Classroom.*

WHEN I was a student, and afterwards when I was an assistant at Glasgow, Lord Kelvin lectured to his ordinary class twice a week, when he was not called away, and his subject was dynamics. About the middle of the session gyrostats made their appearance on the lecture-table, and we had wonderful gyrostatic experiments which filled us with delight, and gyrostatic questions in the weekly class-examinations which were equally productive of dismay. These gyrostatic questions, like many of our exercises in natural philosophy, were often of a numerical character. It is always a good thing to get down to numbers, and it is a most healthful mental discipline to be forced to "get the units right." Our equipment for the solution of these problems was of the slightest, for Lord Kelvin was himself so keenly absorbed in observing the behaviour of the apparatus, that he rather frequently forgot to give us the full dynamical explanation of the curious evolutions which we beheld. I could follow the process of composition of angular momenta, and could see that the axis of resultant angular momentum turned at that rate; but why should that also be the rate of turning of the axis of figure? That was my special difficulty, and it was only afterwards, when I got the idea of steady motion, and saw how the general equation is obtained and how it breaks down into the conditions for steady motion, that the matter became clear. Then I found, moreover, that in the general case there are two possible rates of turning. It is a good thing to stimulate the curiosity of a student to make him find out things for himself: it is also an excellent thing to anticipate his difficulties to some extent, lest he grow weary and faint by the toilsome dynamical way.

The lectures that we had were undoubtedly most interesting and suggestive, though they were not perhaps always directed to the more prosaic topics which formed the staple matter of the degree examination questions for ordinary students. The first experiment made was always that of the equilibrium of this nearly egg-shaped piece of wood, which, scientifically described, is a homogeneous prolate ellipsoid of revolution. Its surface may be imagined to be generated by the revolution of an ellipse about its longer axis. (The diagram, Fig. 1, shows a really egg-shaped solid.) I lay it on its side, and we see that in that position it is stable for fore and aft inclinations, "pitching" I may call the motion, and in indifferent equilibrium for port or starboard displacement, or rolling. This is, of course, all without spin.

If, however, I apply to the solid, as it lies on the tray before me, an impulsive couple with my fingers, so as to make it rotate about one of the minimum diameters (that is, of course, a diameter about which the moment of inertia is a maximum), the solid shows that when spin is applied the equilibrium is unstable. The ellipsoid at once sets itself on one end, and then rotates in stable equilibrium with the long axis nearly vertical. This is a very remarkable result. The centre of gravity has been raised, and the equilibrium is now stable. The spin has altered the conditions of equilibrium completely.

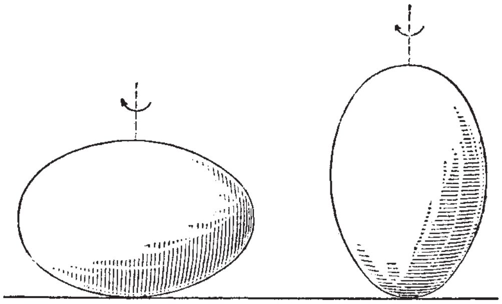

FIG. 1.

Of course, it was pointed out to us that all these phenomena are well shown by the ordinary spinning-top, spun by the unwinding from it of a string when the top has been skilfully thrown from the hand. Schoolboys are not encouraged now (indeed they are *dis*couraged by prefects and other important personages) to play with tops and marbles, and thus many phenomena of spin and collision which some of us used to observe are missed. The swaying round of the axis of a top when rising just after spin to the "sleeping" position, and the similar conical motion of the axis when the top is about to fall, give examples of precessional motion, of, in fact, the astronomical phenomenon called precession of the equinoxes.

Precession was illustrated by the interesting old model of a terrestrial globe which I have here (Fig. 2). You see that the globe is weighted so that a pin projecting from the north pole rolls round a ring, that is, a narrow cone fixed in the earth rolls in the inside of a cone fixed in space. These cones have their vertices at the earth's centre, the axis of the fixed cone is perpendicular to the ecliptic and its semi-angle is 23° 27', that is, an angle equal to the obliquity of the ecliptic. On this ring, which represents the ecliptic, you have the intersections with it of the earth's equator—that is, the equinoxes—and so, as the earth turns, the two intersections move along the ecliptic, the equinoxes precess. The earth, in fact, is a top on which we happen to live, the spin is one turn in 24 sidereal hours, and the conical motion is completed in a period of 26,000 years (Fig. 3). One of our problems was to calculate the diameter of this pin for the earth, or, as it was sometimes put, to find the diameter of the north or south pole! If I remember aright the diameter is about 21 inches.

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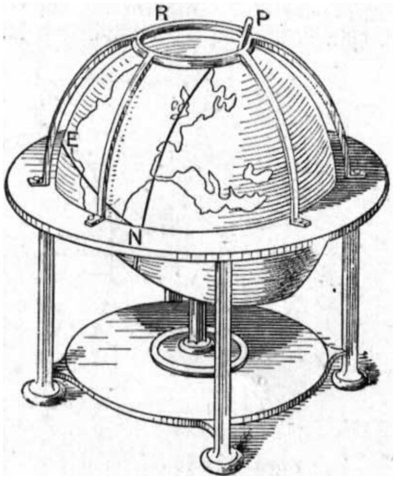
[1] Abridged from the Sixth Kelvin Lecture, delivered at the Institution of Electrical Engineers, on January 28, by Prof. A. Gray, F.R.S.

These were our first gyrostatic experiments and illustrations. I must not omit to mention that the spinning of the ellipsoid was attempted also with each of two eggs, and that with one the experiment always succeeded, and with the other always failed. The reason of this failure and success was interesting; and although some students laughed at the experiment, it nevertheless arrested the attention of all. The contents of one egg were a viscid liquid, the contents of the other had been subjected to a process of coagulation by prolonged exposure to an elevated temperature. In other words, one egg, the one that would not spin on end, was raw, the other had been boiled hard. I now repeat this experiment, which is the scientific solution of the famous problem of Christopher Columbus, to make an egg stand on end.



It is very easy to show, on principles which I hope to explain later, why the solid prolate ellipsoid, the piece of wood, or the hard-boiled egg, sets itself on end when it is spun about one of the shortest diameters; it is not at all easy to show why the raw egg does not.

I shall now say something of Lord Kelvin's papers and work on gyrostatics, taking the various topics more or less in chronological order.

II.—*Dynamical Theory of Rotation of Plane of Polarised Light.*

The first paper in which Lord Kelvin dealt with what may be regarded as a gyrostatic problem is that published by him in the Proceedings of the Royal Society,[2] entitled "Dynamical Illustrations of the Magnetic and the Heliçoidal Rotatory Effects of Transparent Bodies in Polarised Light." He does not in that paper use the term "gyrostat" or "gyroscope," but the equations which are arrived at in the discussion of the dynamical illustrations referred to are in form essentially of the kind which he afterwards called gyrostatic.

The fundamental idea of this paper is one which he developed a good deal in later papers and, from time to time, in his lectures to his students. It is that the rotation of the plane of polarised light transmitted through a solution of sugar or tartaric acid, or across a plate of quartz cut at right angles to the axis of the crystal, is to be explained by a helical structure of the medium; while what appears at first sight to be the exactly similar rotation of that plane, by passage of the light through a piece of heavy glass along the lines of force of a magnetic field, is due to rotational motion already existing in the medium and compounded with the motion produced by the wave of light.

Think (as I heard him once say) of a transparent elastic medium full of little helical hollows of the order of 1/40,000 in. in dimensions, having all their axes turned the same way, so that to an observer looking along them the helices are all right-handed or all left-handed, or at least are preponderatingly in one direction or the other. Such a medium would have the property of transmitting, in the direction of the axes of the helices, waves of torsional displacement at different speeds according as the torsion is right-handed or left-handed.

On the other hand, let us think of a transparent elastic medium in which are embedded in a homogeneous manner innumerable particles describing circular orbits, all of which, or a majority of which, face the same way, and are traversed by the particles in the same direction round. Now let a wave of turning motion of the medium be propagated in one direction or the other, parallel to the axes of the circles. A wave-motion of a certain rapidity in one direction round, say that of the motion of the particles in the circular orbits, will call for the same centreward force, applied to the particles by the medium, as a motion of greater rapidity applied in the contrary direction round. Thus oppositely directed circular motions will, for the same displacements of the medium, have different rapidities of turning (in planes perpendicular to the direction of propagation of the wave); the corresponding waves will travel at different rates, and one will gain on the other.

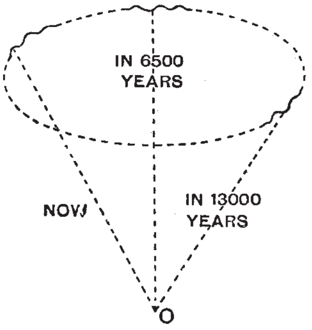


FIG. 3.

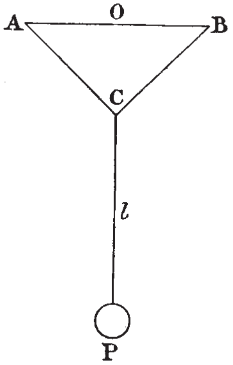


FIG. 4.

The illustration proposed was a double pendulum. A cord (see Fig. 4) is attached at the two ends of a horizontal rod A B, and to the middle point of this cord is fastened a simple pendulum, of length l as indicated. The distance of the bob from the rod is l', that is $l+\mathrm{OC}$. The rod is made to turn with uniform angular speed ω about a vertical axis through its middle point O. The cords are supposed to be of negligible mass and quite flexible, and the bob is a massive particle.

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[2] Proceedings of the Royal Society, vol. viii, p. 150, 1856.

If ω were zero we should have a pendulum the period of which is $2\pi\sqrt{l/g}$ for vibrations in the plane of the paper supposed vertical, and $2\pi\sqrt{l'/g}$ for vibrations at right angles to that plane; and the motion of the bob in the most general form would be compounded of two such oscillatory motions.

When the motion, with ω not zero, is referred to two rectangular horizontal axes of x and y through O, which revolve with the rod, the equations of motion of the bob are

$$x-2\,\omega y+\left(\frac{g}{l}-\omega^2\right)x=0,$$

$$\ddot{y}+2\,\omega\dot{x}+\left(\frac{g}{l'}-\omega^2\right)y=0,$$

where x, y are the co-ordinates of the bob and $\dot{x}$, $\dot{y}$ their time rates of change, and x, y are the accelerations corresponding.

The second terms on the left-hand sides of these equations, $-2\,\omega\dot{x}$, $2\,\omega y$, are in form what were called afterwards by Lord Kelvin gyrostatic terms, and the conditions for the existence of real periods of oscillatory motion in the general case, depending, as the reality of these periods does, on the value of ω, gives us an idea of what he termed in that connection "gyrostatic domination."

In an Appendix to this lecture (see *Journal*, I.E.E.) will be found a synopsis of the solution of this interesting case of motion with some modifications of notation and mode of presentment. The reader may refer also to the original paper.[3]. It is reprinted as Appendix F of Lord Kelvin's "Baltimore Lectures."

The main results may be expressed as follows:—

(1) If a long straight rod, which is unequally elastic in two rectangular directions, or is of unequal diameters in these directions, if of uniform elastic quality (a rod of elliptic section, for example), be rotated rapidly about its axis, and vibrations be maintained in a fixed transverse direction at one end, waves of rectilinear vibration, the direction of which slowly turns round as the wave advances, will be propagated along the rod.

(2) Let the transverse elasticity of the medium (which, to fix the ideas, may be taken, as has already been suggested, as a long straight rod, along which waves of transverse displacement are propagated in the direction of its length) vary with the direction of the transverse, so that it has maximum and minimum values in axial planes at right angles to one another. If this rod be slightly and uniformly twisted about its axis, these planes become heliçoidal or screw surfaces. Think now of a line in space parallel to the axis of the rod. This line will intersect either of these surfaces at points the successive distances apart of which are all equal to the step s of the screw. If the rod be turned about its axis as a whole, each point of intersection will move along the line at a speed v which depends on the rate of turning.

Let a rectilinear vibration be kept applied at any cross-section, say one end, and let the rod be rotated about its axis in the proper direction, and at such a rate that the speed v just specified is equal to the velocity of propagation of the wave produced by the applied vibration. The result will be that a series of waves of rectilinear vibration will run along the rod, without any turning of the plane of vibration in space. In order that the rotation may be rapid, it is necessary that the wave-length, a say, should be many times the step s of the screw.

According to our notation the period of vibration is $2\pi/\mu$, and therefore the velocity of propagation of the waves is $a\mu/2\pi$. But if s be the step of the screw, and ω denote as before the angular speed of rotation, the value of v is $\omega s/2\pi$. Hence we must have $\omega s=a\mu$ or $\omega=a\mu/s$.

The effects of the twist and rotation thus exactly balance one another. The latter (see Appendix) gives a rotation of amount $\frac{1}{4}\pi\lambda^4/\omega^3\mu$ in a wave-length, or a complete turn in $8\mu\omega^3/\lambda^4$ wave-lengths. Hence the effect of a single turn of twist in a length s is equivalent to that of rotation in $8\mu\omega^3/\lambda^4$ wave-lengths.

The dynamical illustration is thus applicable to all the cases of turning of the plane of polarisation of light. There is one point of difference, however, which renders a rotational medium more truly representative of the magneto-optic turning, and is decisive as between a rotational and a structural explanation of the different phenomena. A beam of plane polarised light which has traversed a piece of heavy glass in a magnetic field will, if it be reflected and sent back through the medium, have the turning of the plane doubled by the backward passage, while backward passage through quartz or a sugar solution annuls the turning produced by the forward passage. These facts point, as Lord Kelvin repeatedly urged in his teaching, to a rotational explanation of the magneto-optic effect and to a structural explanation for the other.

III.—*Precessional Motion of a Liquid.*

About twenty years later gyrostatic problems attracted Lord Kelvin's attention in a very special way. From 1875 onward for several years he was much occupied with many things; for instance, he transacted much business connected with submarine cable instruments, eclipsing lights for lighthouses, and compasses and sounding machines. I was one of his assistants, and remember how busy we all were. For the two years from 1875 to 1877 there are set down in the list of his papers four on the subject of gyrostatic action, but of these only two were ever printed, the first and the last. The former was entitled "Vibrations and Waves in a Stretched Uniform Chain of Symmetrical Gyrostats,"[4] the latter "On the Precessional Motion of a Liquid."[5] I shall first give some account of the latter paper, because it contained descriptions and illustrations of gyrostats and gyrostatic action, and shall then return to the former.

The circumstances in which this paper was written were interesting. In 1875 Lord Kelvin (then Sir William Thomson) visited America as one of the judges of Group 25 (Scientific Instruments) of the Centennial Exhibition at Philadelphia. He then met and conferred on scientific questions with some of the most eminent natural philosophers of the United States.

A conversation with Simon Newcomb, in Joseph Henry's drawing-room in the Smithsonian Institution at Washington, led him to doubt the legitimacy of some of his own conclusions regarding the effect of elastic yielding of the crust on the precession and nutation of a liquid earth contained within a solid shell. These conclusions were stated in his paper on the rigidity of the earth,[6] and in §§ 847–8 of the first edition of Thomson and Tait's "Natural Philosophy." For example, he had decided that the yielding of the crust of an internally liquid earth, under the differential attractions of the sun and moon, would produce an effect on the precession so great as to be altogether incompatible with the excellent agreement between theory (on the hypothesis of a solid earth) and observation, as regards precession and nutation.

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[3] *Loc. cit.* above.

[4] Proceedings of the London Mathematical Society, vol. vi., p. 190, 1875. Math. and Phys. Papers, vol. iv., p. 533.

[5] British Association Report, 1876, Transactions of Sections, p. 1.

[6] Philosophical Transactions of the Royal Society, vol. cliii., p. 573, 1863.

Newcomb appears to have suggested that viscosity might possibly render precession and nutation the same as if the earth were rigid throughout. As a direct cause viscosity is inadmissible, but indirectly it is effective, for it at once occurred to Lord Kelvin that a very real cause of agreement between an internally liquid earth and a solid earth as regards precession at least, was probably to be found in the rigidity induced in the interior liquid by its rotation. Thus his attention was directed to the quasi-rigidity of a liquid induced by rotational (or vortex) motion, a subject which, as he told Section A of the British Association after his return from America, occupied his thoughts for weeks almost to the exclusion of all other scientific subjects.

He soon found that if the ellipticity is not too small the shell would not have more precession than the liquid, and that the compound rotating mass would have sensibly the same precessional motion as if it were a single rigid body. He came to the conclusion, however, that the lunar semi-annual and lunar fortnightly nutations would be greatly affected by interior liquidity of the earth.

At the Glasgow meeting of the British Association in 1876 Lord Kelvin was president of Section A, and began his presidential address by quoting the Anacreontic couplet:—

"Θέλω λέγειν Ἀτρείδας,
Θέλω δὲ Κάδμον ᾄδειν"

which begins the complaint of the poet that no matter what hero he wished to sing, his lyre refused to respond to any theme but that of love. Try as Lord Kelvin liked to speak of the scientific men, and scientific inventions that he saw in America, of American education, or the more recent advances of physical science, his thoughts ever came back to the subject of the internal rigidity of the earth and the difficult questions therewith connected. So to this topic he decided to devote the major part of his address. This he did with great effect, clearing away what was doubtful from his former arguments, emphasising and enforcing them as they remained, and reiterating with undiminished confidence his old conclusions.

To illustrate the precession of a rotating liquid he showed later in Section A what he called a liquid gyrostat, and also for comparison various solid gyrostats which had for several years been used for the dynamical illustrations of the natural philosophy class. I have these very gyrostats here on the table, and will use them for a repetition of some of the old historical experiments of the Glasgow class-room.

IV.—*Solid and Liquid Gyrostats. Gyrostatic Experiments.*

The construction of a solid gyrostat is shown in the diagrams before you, which were made, partly by myself, nearly forty years ago (Fig. 5). The instrument consists of a massive flywheel surrounded by a case of brass. The wheel is a disc of thick brass carrying a massive rim, so that the moment of inertia is made as great as possible. One diagram of this slide, as you see, shows a section of the wheel and case, the other a side view of the wheel.

The case is a cylindrical box surrounding the flywheel, with extensions enclosing the axle, for which they are provided with bearings at the ends. Round the case, as nearly as may be in the central plane of the flywheel, is a projecting rim, the edge of which is not quite circular, but rather polygonal with curved sides, and the points of meeting of the sides rounded off. The rim serves to support the gyrostat, as it stands on this glass plate, in some of its evolutions.

The bearings are cups in which the rounded points of hardened steel of the axle run. This is not a good arrangement if the gyrostat is to be subjected to shocks, or to be roughly handled in any way. Oiling also is required, after every second spin at least. In our new gyrostats we use ball bearings designed to resist considerable shocks and stresses without derangement. With these, in some experiments, we have gone up to speeds of about 25,000 r.p.m., and have found the flywheel to be still rotating rapidly after the lapse of forty-five minutes. Also the wheel may be run for several hours with only one oiling.

It will be convenient to show here some of the experiments usually performed in the ordinary class of natural philosophy in Lord Kelvin's time. The multiplicity of subjects put down to be treated in the dynamical part of the course precluded, as I have hinted, any detailed explanations of these experiments. They were carried out, in fact, with the avowed and excellent purpose of exciting curiosity in the minds of the students, and a desire to find out why gyrostats behave in a manner at first sight so anomalous. Interest was certainly aroused in a few, but I fear that the majority despaired of penetrating such mysteries, and sought external help for the mastering of the more hackneyed topics of the degree examinations.

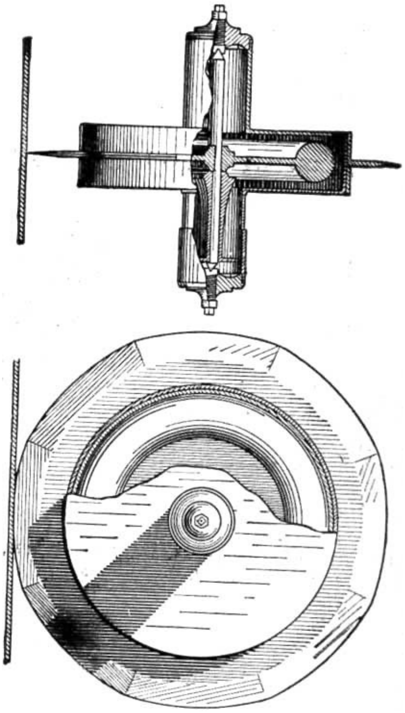

FIG. 5.

The process of spinning excited more interest than any other part of the experiment, for the ordinary elementary student cares more for a little bit of sensation than about the scientific result to be proved. A long cord was laid out on the floor, then the free end passed one and a half, or two and a half, times round the axle of the gyrostat, which was held by the operator, with its axis vertical, in a suitable socket on a table fixed to the floor. An attendant holding the free end ran away with it, slowly at first, then faster and faster, down a long passage and through a large adjoining room, while friction was applied to the cord as it entered the gyrostat case.

For the runner was substituted later a large wheel with grooved rim on which the cord was wound as it was drawn through the gyrostat. I estimate that speeds of about 100 turns per sec. or less may have been obtained in this way. Now, of course, one spins by an electric motor, as I shall presently describe.

I will make one or two of the experiments with the original gyrostats, but it will save time if I repeat the others with some of the new and improved gyrostats invented by Dr. J. G. Gray, whom I am fortunate in having to assist me on the present occasion.

[The usual experiments, illustrating precessional motion of a gyrostat with the axis horizontal, while under the influence of a couple due to the gyrostat overhanging, or to a weight hung on one end of the case surrounding the axle (Fig. 6) were performed.]

This behaviour of the gyrostat is often considered paradoxical, and must, I suppose, be regarded as difficult to explain in a popular manner. At any rate, the popular explanations are as a rule extremely unsatisfactory. Yet in this particular case of horizontality of the axis the matter is simple enough, I think. Let me illustrate by means of this pedestal top (Fig. 7). The curved arrowhead shows the direction of rotation, the projecting arrow the axis of spin, the arrow pointing down can be turned so as to show the direction of the axis of any applied couple. First observe that when I try to retard the precessional motion the axis descends, if I try to accelerate the precession the axis rises. This experiment shows that the horizontality of the axis depends on the freedom of the gyrostat to precess at a certain definite rate. This rate, as we shall see presently, depends on the couple applied by the weight of the gyrostat acting downward in one vertical line, and the pull of the string acting upward in another line nearly vertical, and on the angular momentum of the flywheel.

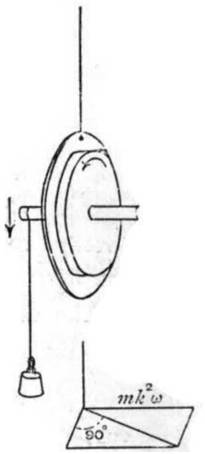

FIG. 6.

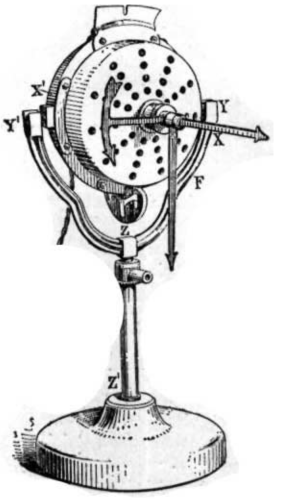

FIG. 7.—Motor-Gyrostat in "Fork and Pedestal" Mounting.

Look at the thing in this way. The axis of rotation round which the flywheel has angular momentum is turning as you see towards the horizontal axis A of the couple, with angular speed, Ω say. Now, and this is the point not recognised as a rule, this motion itself creates a rate of production of angular momentum about the axis A of the couple. For when an axis with which is associated a directed quantity, L say, is turning towards a fixed direction at right angles to it with angular speed Ω, there is a time-rate of production of the quantity associated with the latter direction measured by the product $L\Omega$.

Now the flywheel is revolving with angular speed ω, so that if its moment of inertia is mk^2, it has angular momentum $mk^2\omega$ about the axis R; but with angular speed Ω the axis R is turning towards the instantaneous position of the axis A, a fixed direction to which R is at the moment perpendicular, and, in consequence of this turning, a rate of production of angular momentum $mk^2\omega . \Omega$ exists about A.

Now for the steady motion of the gyrostat, that is, steady turning in azimuth without rising or falling of the axis, it is only necessary that this rate should be equal to the moment of the couple about A, G let us say. Thus we get $mk^2\omega\,\Omega = G$, which gives $\Omega = G/mk^2\omega$.

If I hurry the precession by giving a little impulse, and then leave the gyrostat to itself, the hurried motion, if it continued afterwards in the horizontal plane, would result in a more rapid generation of angular momentum about A than there is moment of couple to account for, and the gyrostat would begin to turn about A, in the direction to cause the angular momentum to be produced at the proper rate, that is the axis would begin to rise. In the same way an impulse towards delaying the precession would cause the axis to begin to descend. In each case the result would be a succession of alternate rises and descents; but the subject of vibrations about steady motion will be found treated in the Appendix, § (5) [see *Journal,* I.E.E.].

Here it is important to remark that there are two possible precessional motions for the same spin and the same inclination of the axis of spin to the vertical, which are given in the theory as the roots of a certain quadratic equation (see Appendix). One is great, the other small. The former to the first approximation does not depend on applied forces, the other does. Lord Kelvin called the former "adynamic," the other "precessional." But in strictness both involve the forces, and they appear as the roots of a certain equation. One of these is at once approximately realised when the wheel is spun fast, the gyrostat set on the plate at rest, and left to itself. The motion is one of small oscillation about the steady motion, which is characterised by slow precession, given very nearly, but not quite exactly, by the same formula as before. The other motion of the axis in the same cone is one of much greater precessional angular speed. The popular expositions which I have seen of gyrostatic steady motion as a rule ignore this second possible motion. It can be realised by proper means.

In strictness we must regard this second precessional motion as characteristic also of the gyrostat when its axis is horizontal, but in that case the precessional angular speed is infinite, and only the slow motion is realisable.

The rule, often stated, that hurrying a gyrostat in its precession causes tilting up of the axis, and delaying the precession causes tilting downward, is true only of the slower more usual precession. For the faster precession exactly the reverse rule holds good. This fact does not seem to be generally known, as the rule is generally stated absolutely.

It is important to notice that if the centre of gravity of the gyrostat is above the point of support, supposed on the line of the axis, the two precessional motions are in the same direction; if, on the other hand, the centre of gravity be below the point of support, the precessional motions are in opposite directions. The faster motion changes sign in passing through an infinite value, when the axis is horizontal.

By the effect of hurrying or retarding the precession was sometimes explained in our lectures the rising and falling of a top spinning on a rounded peg in contact with a rough floor along which the top can move. At first the spin is fast and the slipping is such as to produce a hurrying friction couple which causes the erection of the top. After the spin has fallen off the slipping is the other way and a couple which produces the reverse effect results, and the top falls.

[Experiments were here made with a gyrostat on gimbals, and with a gyrostat mounted on a trapeze hung by the crossed cords of a bifilar suspension. See "Gyrostats and Gyrostatic Action," NATURE, April 10, 1913, to illustrate the stabilising by spin of a gyrostat with two freedoms, both unstable without spin.]

As I have already stated, Lord Kelvin illustrated, by what he called a "liquid gyrostat," the fact that an oblate spheroidal shell filled with water behaves as regards precession as if its contents were solid. Here is the gyrostat with which the experiment was made (Fig. 8). It resembles the ordinary gyrostat, but the case is not completely enclosed, and the spheroidal globe containing water takes the place of the flywheel: these are the only points of difference. I spin the globe in the ordinary way, and you see that in all respects the liquid gyrostat imitates the behaviour of the solid one.

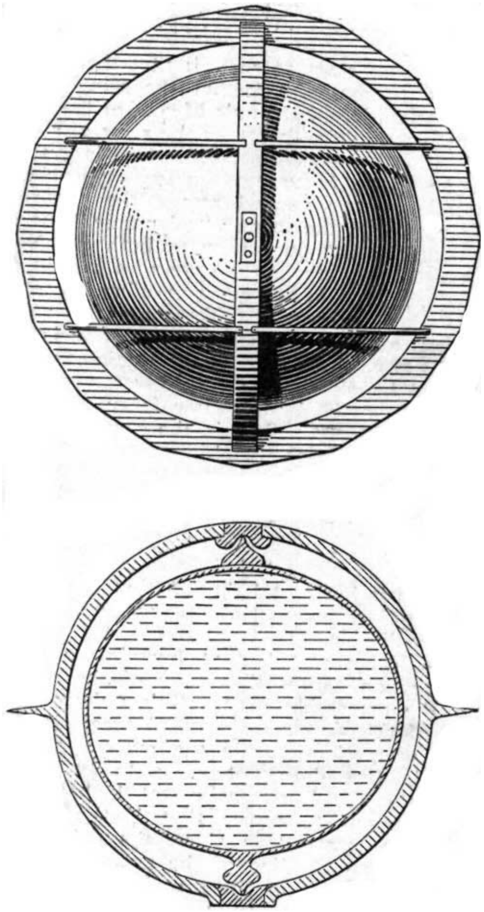

FIG. 8.—Liquid Gyrostat (Oblate).

This spheroid has an oblateness of about 5 per cent.; that is, the difference in length of the polar and equatorial diameters is about 5 per cent. of the length of either. Here, however, is another liquid gyrostat which has about 5 per cent. of prolateness (Fig. 9). I attempt to spin it, and you see that as soon as it is removed from the spinning apparatus its spin has entirely disappeared. In consequence of instability of the motion, the energy of rotation has been entirely transformed into heat, by turbulent motion of the water, into which the rotational motion breaks down. Permanent steady rotation of the liquid globe is impossible.

Oblateness, however, is not absolutely essential for steady rotational motion of a liquid round the axis of figure in a spheroidal case turning with the liquid. It was shown by Sir George Greenhill in 1880 (three years after the meeting of the British Association at Glasgow) that steady motion is possible in a prolate spheroid, if it be sufficiently prolate. The axial diameter, in fact, must either be shorter than the equatorial diameter, or be more than three times as long.[7] As Sir George Greenhill points out, a modern elongated projectile if filled with a liquid would not rotate steadily about its axis of figure, and therefore would not have a definite trajectory as a rifle bullet has; it would turn broadside on to the direction of motion.

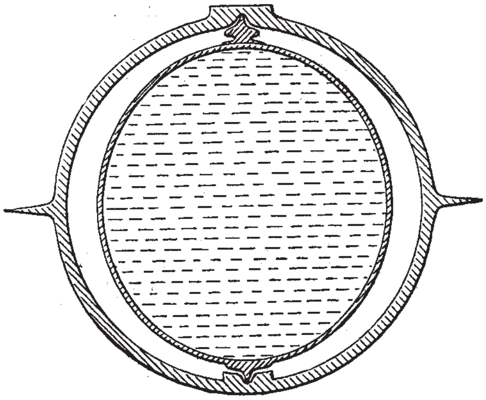

FIG. 9.—Liquid Gyrostat (Prolate).

(To be continued.)

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

BRISTOL.—The Society of Merchant Venturers, in whose Technical College the faculty of engineering is provided and maintained, has decided to offer ten scholarships, tenable in the faculty for three sessions, beginning with the session 1915–16, to the sons of officers in his Majesty's Service who have been killed in the war, and whose mothers or guardians are in needy circumstances.

CAMBRIDGE.—The adjudicators of the Smith's prizes and the Rayleigh prizes are of opinion that the following essays sent in by the candidates are of distinction:—H. Glauert, of Trinity College, on the elliptical form of a rotating fluid mass as disturbed by a satellite, and H. Jeffreys, of St. John's College, on (i) certain hypotheses as to the internal structure of the earth and moon, (ii) on a possible distribution of meteors, to whom the Smith's prizes have been awarded in alphabetical order. A Rayleigh prize has been awarded to J. Proudman, of Trinity College, for his papers on tidal motions.

MR. HERBERT A. L. Fisher, vice-chancellor of the University of Sheffield, has been elected a trustee of the British Museum, in succession to the Right Hon. Sir George O. Trevelyan, Bart., O.M., who has resigned on account of ill-health.

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[7] Proceedings of the Cambridge Philosophical Society, 1880 Encyclopædia Britannica," article, "Hydromechanics."